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From Neurons to Brainpower: Cognitive Neuroscience and Brain-Based Learning

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Abstract

Scientists have learned about the brain in the past five years than the previous 100. Neuroimaging, lesion studies, and animal studies have revealed the intricate inner workings of the brain and learning. Synaptogenesis, pruning, sensitive periods, and plasticity have all become accepted concepts of cognitive neuroscience that are now being applied to education practice. The "Decade of the Brain" spawned a multitude of brain research and educational theories known as "brain-based learning." There is now a movement toward evidence-based teaching as a result of the new information about cognitive neuroscience and education. Large-scale national and international initiatives continue to take place to research, disseminate, and apply brain science to education. Today, multi-disciplinary approaches to current educational practices are viewed as the best method to bridge cognitive neuroscience theory to educational practice.

From Neurons to Brainpower: Cognitive Neuroscience and Brain-Based Learning

This paper reviews the development of cognitive neuroscience, its impact on education, and implications for learning across the life span. Although cognitive neuroscience is a relatively new phenomenon, an historical perspective was sought to gain a complete understanding of its history, developments, and effects on science and education. Extensive database searches were completed which brought to the forefront the recent discoveries in brain science, controversies about how the two disciplines should interact, and promising implications to enhance the quality of learning and affect social policies about education. Today's educators are positioned to revolutionize lifelong teaching and learning based on scientific evidence and collaboration between neuroscience, psychology, and education. This paper presents the following: (a) history and definition of cognitive neuroscience, (b) anatomy of learning, (c) brain-based learning and controversies in education, (d) current applications of cognitive neuroscience in education, (e) future implications for learning throughout the lifespan.

History and Definition

The seeds for cognitive neuroscience were sown many years ago, circa the first decades of the nineteenth century when the study of the role of specific regions of the brain became known as the doctrine of cerebral localization. This occurred in Europe where anatomists determined speech pathology from brain injuries such as strokes and head injuries. Paul Broca located the speech center in postmortem examinations found in the left frontal lobe in 1861. The concept of cerebral dominance began to emerge, with the left hemisphere speculated as being the "leading hemisphere" for most people, with right handedness and the director of higher functions. The right hemisphere was seen as

subordinate to the control of the left hemisphere (Shorbis, 1996; Springer & Deutsch, 1998).

In the 1930's and 1940's brain surgeries were conducted on patients with severe epilepsy, which contributed to the knowledge of hemispheric asymmetry of function in general. It is now clear that both hemispheres contribute to the complex mental activities of human functioning and that hemisphericity is a result of varying gradations or propensities towards linear vs. nonlinear thinking and behavior (Bruer, 1999; Hall, 2005). Cognitive psychology, which focuses on theories and models of normal cognitive function, became established in the mid-1960s, and combined with neuropsychology to become cognitive neuropsychology. This approach is used in cognitive neuroscience to understand the relationship between the brain and behavior (Springer & Deutsch, 1998).

Today, cognitive neuroscience is known as the link between neuroscience, which is concerned with the inner workings of the brain, and psychology, which studies behavior experimentally outside of the brain. Neuroscience explains the brain through various aspects of biology, physiology and chemistry which describes the structure, organization and development of the brain. Psychology is interested in the behavioral impact of various types of input applied to specified contexts (Hall, 2005).

Cognitive neuroscience focuses specifically on understanding higher level processes of cognition via imaging technology, lesion studies, and animal studies. Neuroimaging has enabled scientists to study the human brain in action though such tools as positron emission tomography (PET) scans, functional magnetic resonance imaging (fMRI), and electroencephalograph (EEG) recordings. This has led to the understanding of very intricate processes underlying such things as speech and language, thinking and

reasoning, and reading and mathematics. Insights from cognitive neuroscience may be helpful in supporting established best education practices and may aid in informing educators about new concepts of teaching and learning (Goswami, 2004). The fascination with brain science has spawned interest in application of its new findings to teaching and learning, and has taken off in a new specialty called brain-based learning (Bruer, 1999).

The 1990s were declared the "Decade of the Brain" in the United States by President George Bush in his presidential proclamation in July of 1999. This resulted in a large research movement about the functioning and development of the brain which led to international interests on the topic throughout the decade (Organization for Economic Co-Operation and Development, 2002). Initial scientific findings were published, and because of the fascination with the speculations about its relevance to improving learning, it quickly became directed at general readership, teachers, and parents pronouncing revolutionary endorsements of brain-based learning. Some publications suggested possibilities of the application of credible findings to education practice; while some enthusiasts over-simplified the findings and erroneously applied cognitive neuroscience concepts that were merely speculations. The latter have been described "neuromyths," which will be described later.

Organizations that contributed to the corpus of academic research included The Organization for Economic Co-Operation and Development (OECD), Economic Social and Research Council (ESRC), Education Commission of the States (ECS), National Institutes for Health (NIH), and the Scottish Council for Research and Education (SCRE).

All have made significant large-scale contributions to the state of the science, and continue research efforts to apply theories of cognitive neuroscience to education.

The OECD was organized in 1960 to support democratic countries in the areas of economic growth, expansion, and world trade. In 1999 a division of the OECD, the Center for Educational Research and Innovation (CERI) launched a massive project for 30 member countries on learning science and brain research to encourage collaboration between learning sciences and research, and researchers and policy makers. Three international forums were held on the topics of brain mechanisms of early learning, youth learning, and aging. A massive report summarized what has been learned, and the project continues to focus on research in all of these areas in addition to lifelong learning (Hall, 2005).

The ESRC is an independent research organization in the United Kingdom with an international focus on funding research and training in social and economic issues (ESRC, 2005). A division called the Teaching and Learning Research Programme (TLRP) supports and develops educational research leading to improvement in outcomes for learners of all ages, in all contexts of education. One such project reported on the comprehensive developmental and cognitive neuroscience studies that are informative about learning and its possible relevance to research on teaching and learning (Blakemore & Frith, 2000).

The ECS was founded in 1968 in an effort to have the United States (US) federal government and the private sector come together to improve education across all 50 states. Its aim is to improve and strengthening education policy and policymaking at the state level by providing workshops and publications on a variety of topics in education.

ECS supports and participates in various networks for legislators to promote the sharing of information, ideas and resources at the state and national levels (ECS, 2005).

The NIH has a division under the National Institute of Neurological Disorders and Stroke (NINDS), called Human Cognitive Neuroscience, whose goals are to understand cognitive and physiological foundations of normal and impaired aspects of the central nervous system (NINDS, 2005). They carry out research on cognitive neuroplasticity in the human brain and examine how brain imaging shows changes in response to normal learning. For example, a new study about the rules of the primitive brain reveals how quickly people learn associations such as stopping at a red light. It challenges the current view of how specific brain areas help people learn rules and behave accordingly. The findings may help to reveal how the brain organizes and orders its functions and processes which could be helpful in education practice in improving teaching and learning strategies.

The SCRE was founded in 1928 and provides a range of educational research, information and advisory services to organizations, institutions and individuals. Its focus is on research of all phases of education, formal and informal, from pre-five to higher education and includes collaborations with the University of Glasgow's Faculty of Education (SCRE, 2005). An inclusive research report has been published about the most recent developments about neruoanatomy, imaging tools, application of neruocognitive theories to education, and future research needed (Hall, 2005).

From the cumulative research of the organizations listed above, there has been more learned about the brain in the past five years than the previous 100. Nearly 90 percent of all neuroscientists who have ever lived are alive today (Brandt & Wolfe,

1998). However, in education, there has been difficulty in the application of cognitive neuroscience to education practice, which involves knowledge of human behavior to promote effective teaching and learning. Despite the extraordinary progress, brain research has not yet found an application in theory or practice of education (Blakemore & Frith, 2000). Thomas T. Bruer (1997), president of the James. S. McDonnel Foundation, which supports international research in biomedical science and education projects, released an influential statement claiming the bridge between cognitive science and education is too wide, and has little to offer teachers in informing classroom practice. Today, multi-disciplinary approaches to current educational practices are viewed as the best method to bridge cognitive neuroscience theory to educational practice (Blakemore & Frith, 2000; Geake & Cooper, 2003; Hall, 2005).

Anatomy of Learning

Tools used in brain imaging technology have provided neuroscientist with a large volume of data about brain structure and function beginning in the 1970s when advances in physics and computing came together. Prior to this time, the human brain was studied mainly in post mortem examinations. It was discovered that because of the complexity of the brain, there is no one-to-one relationship between anatomical split-brain function-behavior for higher order processing. Today brain function is described as "ongoing interactions across scale, between localized and distributed neuronal networks, which are engaged according to situation and task demands" (Gordon, 2000, p. 233-234). Behavior is associated with multiple neural networks rather than specific anatomical sites. A description of the most recent brain imaging techniques follows with applications to the human brain and learning.

The computed tomography (CT) is a scan that allows X-rays to pass through the brain that show "slices" of the brain related to the density of the tissue. The magnetic resonance imaging (MRI) uses a magnetic field to capture hydrogen atoms in white and grey matter, causing contrast between the two from a variety of angles. Functional magnetic resonance imaging (fMRI) shows the white and gray matter with cortical blood flow in response to activation due to changes in deoxyhemoglobin to hemoglobin in specific brain areas. Electroencephalography (EEG) measures activity in dendrites in cortical neurons using recoding disks on the scalp. Event related potentials (ERP) reflect the integrity of sensory neural pathways using an EEG set-up in addition to computer controlled stimulus. Magneto encephalography (MEG) measures the distribution of magnetic fields outside the head which determine their electrical source within the brain and is used to complement EEG and ERP methods. Regional cerebral blood flow (RCBF) is measured using an inert gas that is introduced into the body via inhalation or intravenous injection. The gas saturates the brain then shows cortical activity after it is cleared from the grey matter. Single photon emission computed tomography (SPECT) uses radioisotopes intravenously which become trapped into neurons in proportion to the activity of the substance. Three dimensions can be seen showing cortical and subcortical activity. Positron emission tomography (PET) uses an isotope that is naturally used by the brain which collides with electrons giving off gamma rays that are detected outside of the head. Images are constructed reflecting slices of cortical and subcortical distribution of the brain's activity (Gordon, 2000).

Application of the above imaging techniques in education are based on the assumption that any cognitive task makes specific demands on the brain which will be

met by changes in neural activity. Some techniques are used alone and some are best used in combination. The most commonly used imaging methods include the EEG, ERP, MEG, MRI, fMRI, PET, which are used to investigate localization of function in the brain. One newer method includes the transcranial magnetic stimulation (TMS) in which magnetism creates a temporary disruption in brain activity which indicates whether it is related to a particular function. Another is optical topography (OT) which uses near-infra-red spectroscopy (NIRS) to study blood flow. Both need further development to determine their effectiveness in learning (Blakemore & Firth, 2000; Goswami, 2004).

In addition to imaging techniques, lesion studies reveal behavior consequences of brain damage and give an indication of the functionality of certain areas of the brain which can be viewed in animals and humans (Blakemore & Frith, 2000). Animals have also been used in neuroscientific studies through surgery, effects of drugs, measurement of electrical brain activity, and behavioral studies (Hall, 2005). Byrnes and Fox (1998) believe that these studies have limitations because animals are less flexible in their behavior than humans who possess higher-order thinking skills. The combination of the above methods can offer possibilities for education in the areas of early diagnosis of special education needs, monitoring and comparison of the effects of educational input on learning, an increase in understanding individual differences and best ways to accommodate learning styles throughout the life span (Hall 2005).

Learning at the molecular level has been explained by neuroscience through the techniques described above. The nervous system's basic unit, the neuron, has many different shapes and sizes. The brain contains 100 billion active neurons. Gaps between the neurons, synapse, carry the electronic signal through substances called

neurotransmitters between the neuron and the end of the neuron, the axon. The neurotransmitters induce a chemical reaction on the end of the adjacent neuron, the dendrite. This reaction signals transmission to the next neuron which travels through the brain, and so on (Galles, 2004).

Repetition of the transmission of neurotransmitters, as seen in learning, modifies the neurons in the brain, which leads to dramatic growth of axons, dendrites, and the number of connecting neurons. This process is called synaptogensis and occurs in different parts of the brain at varying times. The developing brain produces more than enough synapses than is necessary, thus a "pruning" of the synapses takes place by late adolescence which appears to be a "fine tuning" process resulting in fewer synapse in the human adult. This is not a time of loss of brainpower, but an adaptive measure to learn and master diverse, complex, and abstract bodies of knowledge. The brain is known as a "plastic" structure which refers to its ability to change its functioning as a consequence of learning, and past environmental experiences (Blakemore & Frith, 2000; Bruer, 1999: Goswami, 2004).

Other discoveries about the brain include the existence of two hemispheres, each with 4 lobes which are associated with cognitive functions. The brain posses evolved modular structures in which elementary functions are widely dispersed. It is a parallel processor in which brain activity takes place simultaneously, and not one after another in a sequential fashion. The brain has high connectivity which indicates that there are a very high number of connections between neurons that imply a high degree of interaction in various parts of the brain. It has a high redundancy quality, which demonstrates that the brain performs more tasks than it requires. The brain operates in a probabilistic

manner, meaning that conviction to a thought or idea does not need to be achieved for a function to be preformed (Byrnes & Fox, 1998; 0ECD, 2002).

All of the above findings indicate that functions of the brain are not necessarily pre-determined by birth, but can alter as a result of environmental differences. It has become clear that synaptic connections within the brain can change and re-form throughout life as a result of learning, or in response to injury such as a stroke. It can be concluded that the brain retains its plasticity over a lifespan, which has significant implications for teaching and learning throughout life (OECD, 2002).

"Brain-based Learning" and Controversies in Education

The findings of an estimated 50,000 neuroscientist researchers in Europe, and a similar number in the United States, led organizations from the scientific and academic arenas around the world to hold symposiums and publish reports about how neuroscientific research could be applied to education, as mentioned previously, which provided starting points for many new methods of teaching and learning. The movement for "brain-based learning", or "brain-compatible learning" gained momentum in the mid 1990's when the Carnegie Corporation and Education Commission of the States (ECS), among others, released reports attempting to show how the findings from neuroscience could be applied to education policy (Bruer, 1999; Stover, 2001).

Caine and Caine (1990) devised 9 principles to guide this revolution, which some educators found to be simple, restated beliefs about successful teaching and learning. The main idea of brain-based learning is that of maximizing the moment of learning to produce extraordinary results to those who are taught (Reardon, 1998). The principles are as follows: (a) The brain is a parallel processor. This indicates that the brain

processes information in a multi-modal, multi-path fashion. Indications for teaching include using complex multi-sensory immersion environments. (b) Learning engages the entire physiology. The brain is affected by such things as sleep, nutrition, and exercise; therefore these functions should be attended to in order to enhance learning. Engaging the student in maximizing various physiological states such as using a variety of teaching strategies is advocated. (c) The search for meaning is innate and occurs through patterning. The brain's goal is to turn data into meaningful information. The quality of meaningful knowledge increases when information is related to a learner's past experiences and knowledge, providing stability and familiarity. (d) Emotions are critical to patterning. The learner must be in a positive state of calm anticipation for optimal learning to occur. This implies that student-centered strategies such providing an emotional climate of mutual respect, allows for the most favorable learning experiences. (e) Every brain simultaneously perceives and creates parts and wholes. Both sides of the brain are involved in nearly every activity. For example, teachers can provide a sequence of small steps in learning material, at the same time as the application of "big picture" details takes place. (f) Learning involves both focused attention and peripheral perception. The brain responds to the entire sensory context in which teaching and learning occur. Teachers can support learning by using peripherals such as color, decorations, sound, and smells. (g) The brain remembers best when facts and skills are embedded in contextual memory. Information is stored in relationship to past circumstances and associations. Students' learning can be enhanced by using narrative pedagogy and metaphors. (h) Learning is improved by challenge and inhibited by threat. The brain is stimulated by rich, challenging situations occurring in safe environments for

risk taking, such as in the use of debates. (i) Each brain is unique. Experience, genetics, and environment all play a part in the formation of the brain, which is as unique as human fingerprints. Diversity in thought and ways of knowing can be encouraged by educators.

The enthusiasm for these new findings and principles led to an overabundance of populist brain science literature from memory to awareness to perceptions of reality that became top sellers (Geake & Cooper, 2003). News and television programs touted brain-based learning as the "wave of the future" to improve education and parenting. State policy makers in a number of states in the US expanded preschools, parent training, and other childhood initiatives in an effort to improve learning. Corporations sprung up with populist literature claiming faster and more efficient ways to learn and remember information (Hiltibran & McKinney, 2000).

This new movement sparked a debate about the relationship between neuroscience and education. A backlash from skeptics claimed that enthusiasts had over-simplified neuroscientific research and over-interpreted its findings (Bruer, 1997). A number of "neuromyths" were created including ideas about "right and left brains", "critical periods" for learning in early years, and "enriched environments".

The neuromyths were first described by Bruer (1997), and have had implications on both child and adult learning as a result. The literature has been abundant with information about the existence of brain laterality, or the idea that the two halves of the brain work fundamentally in different ways. The left brain is usually characterized as the logical half, adept at reasoning, problem-solving, and language. The right brain is seen as the intuitive and creative side that is involved with images rather than words (O'Boyle & Gill, 1998). This idea is a gross over-simplification that is not supported by brain

research literature (OECD, 2002). Concept formation is more unitary and not as readily separable into right and left-brain functions (Bruer, 1999; Geake & Cooper, 2003; Goswami, 2004; Hall, 2005; O'Boyle & Gill, 1998; Shorbis, 1996).

The idea of brain laterality came from studies on "split brain" patients who had the corpus callosum severed as a treatment for epilepsy. In the normal, healthy adult human brain, such gross characterizations do not exist. Almost all functions of any complexity are found to consist of a series of functions which are distributed throughout the brain that require areas of the brain to work together (Shorbis, 1996). Acceptance of brain laterality or hemisphere dominance has become general knowledge about teaching and learning (Bruer, 1999).

The second myth is that of critical periods for brain development, which came from animal studies, claiming that the first three years are critical to learning because of the synaptogenesis that occurs during this time. It was erroneously thought that stimulating a child with such things as language acquisition, to take advantage of this rapid growth in synapse, would increase intelligence before the pruning period took place in the development of the brain. It is now known that the synaptogenesis and pruning are normal aspects of human development, and do not indicate a change in brain power as the human brain matures. Neuroscientists have ceased using the term critical periods and now classify them as "sensitive periods" or "windows of opportunity" (Bruer, 1999, Hall, 2005).

The third myth is that of providing an enriched environment for development of young minds. This idea was based on a study of rats that were brought up in either "enriched" or "deprived" environments. The enriched rats were found to have developed

a greater synaptic density in their brains than those who had been deprived. The popular thought that came from this research was that early educational enrichment for humans could increase intelligence or learning capacity before the pruning of the synapses occurred. For example, playing classical music to infants was thought to increase their intelligence as adults. However, there is no evidence that supports the linking of synaptic densities and improved learning or intelligence in humans. In addition, there is no evidence that increased early synaptic densities in humans are related to improved intelligence in later life (Bruer, 1997; OECD, 2002).

The rat studies also showed that the effects of the environment were applicable to all ages, not just the young rats. In effect, what was provided was possible evidence for the plasticity of the brain throughout the life span. Bruer (1997) went on to elaborate that enrichment in the early education of humans is reflective of one's cultural and class values, which is not supported by neuroscience. Davis (2004) argued that learning occurs "outside the skin" which includes the conditions of social, cultural, and natural environments that must be taken into consideration beyond the applications of the findings of neuroscience, which focus on the events and process that occur "inside" individuals.

Brain laterality, critical periods, and enriched environments are the most prevalent neruomyths that are evident today, and represent how some educators have uncritically embraced neuroscientific conjecture. Other myths that are in circulation include the "gendered brain" and "implicit learning." Gender differences in brain function may have some basis in fact, and may have some implications for education, but the complexity of biological and cultural bases for these differences make future research necessary before

applications can be made to education practice (Ginger, 2003). Implicit learning is that which occurs unintentionally, thus may have some implications in preventing distractions during learning. On the other hand, there is speculation about whether implicit learning is applicable to cognitive tasks (Goswami, 2004).

The misguided conclusions, or neuromyths, described by John Bruer (1997), are cause for concern for educators, who should be encouraged to keep abreast of recent findings and cautious about adopting new strategies that have not been proven. For example, one school system in Billings, Montana invested $30,000 in a three-to-five year plan for staff development on brain-compatible learning. They disseminated information on the latest scientific findings to other educators in the state. Another example can be seen in brain-based teaching strategies that have been implemented in Morgan County, Georgia, but only after they have been scrutinized by knowledgeable educators. The results of the students' learning are subsequently monitored. The initiation of staff development programs and brain-based teaching strategies has revealed higher student test scores as a result (Stover, 2001).

Current Applications

Neuroscientific findings in the processes of synaptogenesis, pruning, and plasticity have now become accepted scientific information about the development of the human brain. Synaptogenesis and pruning are not confined to childhood years, and plasticity, in response to new environmental demands, occurs throughout life. Sensitive periods exist for certain types of learning, such as language pronunciation, but are not confined to the early years of childhood, and are not as significantly important as it was initially believed. The idea of "use it or lose it" is an exaggeration of the truth, and it is

now known that lifelong learning does indeed occur. In other words, "you can teach old dogs new tricks" (Hall, 2005; OECD, 2002).

Grass roots examples of current uses of brain-based learning are described by Stover (2001) who contends that educators need to have a better understanding of how the brain works and its educational value. One example of how neuroscience research has been put to practice is by providing choices to students about learning based on inherent interest and motivations, which adheres to the idea that learning occurs in interactive modules in the brain. A second example includes breaking up daily lessons into smaller segments to extend other classes to allow project-oriented study, thus allowing for synaptogenesis to occur in different parts of the brain at varying times. A third is described as developmentally appropriate activities used to stimulate brain growth and improve the ability to learn, which takes advantage of the sensitive periods for learning.

Another accepted application of the brain-compatible approach has been seen in the area of experiential education, or "learning by doing" (Roberts, 2002). Two examples include Project Adventure and Outward Bound. Project Adventure (2005) seeks to develop responsible individuals, productive organizations and sustainable communities, through experiential learning. Outward Bound (2005) has outdoor programs that allow students to develop self-reliance, responsibility, teamwork, confidence, compassion, environmental and community stewardship. These two programs have been well documented as successful implementations of experiential pedagogy.

Principles of brain-based learning are followed in experiential learning with application of principles such as patterning, parallel processing, and challenges to enhance learning. For example, one principle contends that the search for meaning is

innate and occurs through patterning. Educators "chunk" information together as a tool for learning in a meaningful way. A second principle, the brain is a parallel processor, can be utilized using learning through rich, multifaceted and multi-sensory environments. A third principle, learning enhanced by challenge and inhibited by threat, can be used by educators to encouraged students to up-shift their responses to learning into higher order thinking by setting high expectations in non-threatening environments.

Synaptogenesis, pruning, and plasticity have become accepted in educational communities that endorse brain-based learning or brain compatible learning. Many of these strategies have been used for years, and neuroscience is, in effect, confirming good teaching strategies and can give suggestions for educators to fine-tune their instructional techniques. Programs to keep educators informed through faculty development and monitoring of results of student learning has been seen as ways to improve learning as portrayed in these above examples. This has implications for future educators who can cautiously and wisely implement appropriate findings from brain research in education practice.

Future Implications

There is no "grand theory" of learning that is emerging from neuroscience, but it appears as if collaboration between cognitive neuroscience, psychology and education will need to occur in the journey of the formation of many applicable theories. There is still a long way to go in the direct application of cognitive neuroscience to education, although it is shedding light on some areas such as second language learning, the relationship between form and meaning, specific deficits such as dyslexia, and understanding numbers (Geake & Cooper, 2003; Galles, 2004; Hall, 2005). Other

significant areas of the use of cognitive neuroscience in education include the link between emotions and learning, the impact of educators on learners, the neural circuits of educators, and evidence-based teaching. National and international initiatives are continuing to pave the way for future research directions in the application of cognitive neuroscience to education.

The links between the emotional brain (amygdala and hippocampus) and the reasoning part of the brain (frontal cortex), for example, have been shown that when impaired, as in stress or fear, learning is compromised. The amygdala is thought to be associated with retention of memories and emotional experiences in both human imaging and animal studies. This has clear implications for education in the combining of positive emotions to influence learning and memory. Uninteresting learning environments are most likely unproductive and ineffective in acquisition and retention of knowledge (SCRE, 2001).

Neuroscience has not yet studied neural changes accompanying mental processes and inferences made by educators. Questions such as whether there are specialized neural circuits for different aspects of teaching may soon be evident through the use of neuroimaging techniques. It is a thought-provoking idea for cognitive neuroscience, psychology, and education to collaborate in investigating teaching and its impact on learning. It could lead to important information relative to the design and delivery of educational curricula as well as the quality of teaching itself (Goswami, 2004). Educators should not be apprehensive about the findings of cognitive neuroscience, as many of them may support high-quality education practices based in empirical evidence (Geake & Cooper, 2003).

The link between cognitive neuroscience, psychology, and education can help to bolster the case for evidence-based teaching and learning in the future. The move for educators toward scientific evidence-based practice is just beginning, and the disciplines of cognitive neuroscience, psychology and education can collaborate to advance education science through qualitative and quantitative research methods (Geake & Cooper, 2003).

An example of the movement toward leadership in evidence-based teaching can be seen in the nursing profession. The National League for Nursing (NLN), Nursing Agenda for Nursing Education Research has identified priorities to promote excellence in nursing science and knowledge development for nursing education in efforts to bridge education and practice. The priorities include (a) innovation in nursing education: creating reform, (b) evaluation in nursing education: evaluating reform, and (c) development of the science of nursing education: evidence-based reform (NLN, 2003).

According to the NLN (2003), evidence-based innovative teaching in nursing education is needed to develop the science of nursing education. The majority of nurse educators do not have knowledge of education strategies to use in their education practice, and many teach according to tradition or favorite practices. Education surveys, conferences, and publications have initiated the move toward evidence-based teaching. Nursing education would clearly benefit from the findings of collaborative efforts between cognitive neuroscience, psychology, and education. Nursing education encompasses adolescent and adult populations, and the concepts of synaptogenesis, pruning, and plasticity all apply to the fundamental teaching and learning that occurs throughout the lifetime.

The movement for brain-based education is still taking place, both nationally and internationally, and continues to provide significant research in cognitive neuroscience and education. Two current, extensive initiatives include the U.S. National Science Foundation Program (NSF), and the already mentioned OECD "Brain and Learning Project." Both are very ambitious initiatives that can help educators understand teaching and learning at all levels (Galles, 2004).

The NSF Program is called the "Science of Learning Centers" which is designed to coordinate all disciplines that relate to science and education ranging from psychologists and biologists to mathematicians, anthropologists, and educators. Its mission is to offer awards for large-scale, long-term centers that will extend the frontiers of knowledge on learning of all types and create the intellectual, organizational, and physical infrastructure needed for the long-term advancement of learning research. For example, discoveries have been made in the use of tiny "nano-wires" in the brain to detect the activity of neurons adjacent to blood vessels, which reveals more sensitive data than the PET and fMRI scans. Implications for treating diseases such as Parkinson's disease in addition to use in education are evident (NSF, 2005).

The OECD "Brain and Learning Project" (2002) have had its third Lifelong Learning Network Meeting in January, 2005, and have concluded that the main findings from brain science of significance to education concern plasticity (the ability to adapt appropriately to changes in the environment) and periodicity (the claim that there are critical/sensitive periods for learning). However, there does remain some controversy between each of the 40+ branches of the new science. It was proposed that education needs to have a consensus about what common ground among neuroscientists is, what

currently disputed territory is, what controversial claims are, and what can be safely dismissed as neuromyths (Coffield, 2005).

Concerns from the OECD January meeting include the topics of (a) biology, culture and context, (b) the complexity of learning, (c) the dependence on animal studies, and (d) technical language. Human behavior must be understood with reference to not only neuroscience, but culture and situational context. Learning is very complex, and the educator needs to take into account the characteristics of students, teachers, and context. Research on rodents, cats, and monkeys do not represent the culture of humanity, and there is concern over the controversial issue of the morality of using animals in experiments. Technical language of neuroscience will need to be explained to non-experts if it is to be applied to educational practices (Coffield, 2005).

Future questions that may be answered by the interdisciplinary venture of cognitive neuroscience, psychology, and education include education issues, such as (a) what age to begin school, (b) differences in the way males and females learn, (c) the effectiveness of remedial interventions, (d) interventions for the educationally disadvantaged, (e) best methods to enhance learning and memory across the lifespan, (f) the effects of education on political agendas for societal improvements, (g) genetics and learning, (h) emotions and learning, (i) moral implications of educational interventions towards social policies, (j) aging and cognitive fitness, and (k) intergenerational learning.

Brain science will continue to provide micro-level information about learning, but it most likely will not have clear answers to the challenges of education and complex social issues without input from many disciplines. There is a need for a new profession of educationally sensitive brain scientists and neuroscientifically knowledgeable

educators to plan and produce innovative, informed leaders in the field of cognitive neuroscience (Blakemore & Frith, 2000).

In conclusion, it is known that synaptogenesis, pruning, plasticity and periodicity affect learning throughout the life span as seen in the advances of neuroimaging, lesions studies, and animal studies of neuroscience. Educators must be cautious in the application of the findings of cognitive neuroscience, and must continue to seek information that is based in rigorous, credible research. Recent areas of research in cognitive neuroscience include emotions in learning, the effects of teaching on the brain, and brain science of educators. There is a new movement toward leadership in evidence-based teaching as seen in the nursing profession. New large-scale initiatives have been set in motion to bring together international, multidisciplinary approaches to research, dissemination, and application of new discoveries about the brain. Areas of concern continue due to the complexity of political and social implications of the new findings, dependence on animal studies, and technical language. There is a need for new professionals who are knowledgeable in the areas of cognitive neuroscience, psychology and education to research, interpret, and disseminate scientifically based methods of teaching and learning to make improvements in outcomes of learners of all ages today and in the future.

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